ENGINEERING AIDS AND DESIGN GUIDELINES FOR CONTROL OF SEDIMENT IN SOUTH CAROLINA

K. F. Holbrook, P.E., P.H.
Project Manager

Woolpert LLP
8731 Red Oak Blvd., Ste 101
Charlotte, NC 28217-3975

J. C. Hayes, P.E.
Professor and Head

Agricultural and Biological Engineering Department, Clemson University
Clemson, SC

B. J. Barfield, P.E., P.H.
Professor and Head

Agricultural and Biological Engineering Department, Oklahoma State University
Stillwater, OK

A. W. Fogle
Hydrologist

Kentucky Geological Survey, University of Kentucky
Lexington, KY

BIOGRAPHICAL SKETCHES

K. F. Holbrook, P.E., P.H.

K. F. Holbrook, has over 15 years experience in erosion and sediment control and is presently the Charlotte Water Resources Group Manager for Woolpert, LLP in Charlotte, North Carolina. He is a registered professional engineer in South Carolina, North Carolina, Kentucky and Tennessee. He holds a B.S. Degree in Agricultural Engineering from the University of Kentucky and an M.S. Degree in Agricultural Engineering from Clemson University. He co-authored the S.C. Stormwater Management and Sediment Reduction Act of 1991 and authored the regulations to implement this law. Currently Mr. Holbrook is working with the Louisville-Jefferson County Planning Commission and the Louiseville Jefferson County Municipal Sewer District to develop a local ordinance for erosion prevention and sediment control.

J. C. Hayes, Ph.D., P.E.

J. C. Hayes holds B.S. and M.S. Degrees in Agricultural Engineering from Clemson University and a Ph.D. Degree in Agricultural Engineering from the University of Kentucky. He is currently Professor, Chair and Department Head of the Agricultural and Biological Engineering Department at Clemson University. He has authored several textbooks, articles, professional papers and taught many short courses as well as extensive research in erosion control and sediment transport with a focus on vegetative filters.

A. W. Fogle

A. W. Fogle holds B.S. and M.S. Degrees in Agricultural Engineering from the University of Kentucky and is currently employed by the Kentucky Geological Survey as a Hydrologist. He has authored numerous articles on hydrologic and hydraulic issues. He is presently in charge of establishing the surface and groundwater monitoring program and developing a Geographical Information Database Management System for the University's new Agricultural Research Farm in Woodford County, Kentucky.

B. J. Barfield, Ph.D., P.E., P.H.

B. J. Barfield holds a B.S. Degree in Civil and Agricultural Engineering and a Ph.D. in Agricultural Engineering from Texas A&M University. He is currently Professor, Chair and Head of the Agricultural and Biological Engineering Department at Oklahoma State University. He has authored several textbooks, articles, professional papers and taught many short courses as well as extensive research in the area of erosion and sediment transport.

ENGINEERING AIDS AND DESIGN GUIDELINES FOR CONTROL OF SEDIMENT IN SOUTH CAROLINA

K. F. Holbrook, P.E., P.H.
Project Manager

Woolpert LLP
8731 Red Oak Blvd., Ste. 101
Charlotte, NC 28217-3975

J. C. Hayes, P.E.
Professor and Head

Agricultural and Biological Engineering Department, Clemson University
Clemson, SC

B. J. Barfield, P.E., P.H.
Professor and Head

Agricultural and Biological Engineering Department, Oklahoma State University
Stillwater, OK

A. W. Fogle
Hydrologist

Kentucky Geological Survey, University of Kentucky
Lexington, KY

ABSTRACT

Recent regulations for storm water management and sediment control have created much interest in the use of BMPs for water quality protection. Federal and state laws have given rise to many local ordinances and programs designed to meet goals and objectives of clean water. Many east coast states have had this type of legislation on the books for the past 20 years. In the late 1970's and early 1980's computer models were developed to assist with the design of BMPs. These models were cumbersome and awkward by today's standards. However, little has changed with some of these early models.

In 1991 South Carolina passed a state law to regulate storm water and sediment discharge from land disturbing activities. This legislation is very aggressive requiring removal efficiencies for sediment reduction of 80 percent. The only way to meet this requirement in design was to use the out of date computer models. Many BMPs could not be modeled directly by existing models. Therefore, the regulated community, regulators, and academia formed a partnership to develop an accurate but simplified method to predict sediment removal efficiencies from commonly used BMPs. These methods were based on the field conditions and soil types specific to South Carolina.

The SEDIMOT II model was modified for South Carolina conditions and simulations of many different scenarios in each major land resource area were done and analyzed. Charts were developed for performance of sediment ponds in upland areas and in lowlands; rock ditch checks in fine, medium, and course soils; silt fence and rock filters.

Benefits of this effort reduced design time, decreased turn around time for permits and reduced cost for the development community, and improved water quality.

INTRODUCTION

South Carolina can be characterized by four major physiographic regions or land resource areas— piedmont, sand hills, coastal plain, and tidal area. Simulations using a modified version of SEDIMOT II estimated the efficiency of structures for sediment control. Many different treatments were applied to these regions to develop engineering aids for design of sediment ponds, silt fence, and ditch checks. Treatments included multiple watershed sizes and shapes, land uses, and soil textures in each resource area. The evaluation included a range of slope lengths, pond dimensions, watershed shapes, as well as other factors required for the specific structures. Hydrographs and sedigraphs were generated for each scenario and watershed. Then sediment controls were applied to each condition and a comparison was made of the sediment removal efficiency. Graphs and charts were developed for design to avoid the use of traditional rules of thumb. The Engineering Aids and Design Guidelines are a compromise between complex site specific computer simulations and simple rules-of-thumb.

BACKGROUND

Federal and state regulations have been implemented that require the control of storm water runoff and sediment discharge. Regulations were implemented in 1992 as a result of Clean Water Act Amendments of 1987. These regulations are known as the NPDES permit requirements for construction, industrial and municipal activities. Some states have implemented storm water management regulations and/or erosion and sediment control regulations. South Carolina passed a state law for storm water management and sediment reduction in 1991. This is one of two state laws in the USA combining storm water management and erosion and sediment control into one law and regulation. The first state to pass this type of legislation was Delaware.

The South Carolina law is unique because it requires a design performance standard of 80 percent removal efficiency of total suspended solids (TSS), or an effluent limit of 0.5 ml/l settleable solids (SS). Both of these standards are based on the 10-year, 24-hour design storm event during the land disturbing activity.

Effectiveness of control is determined by either a performance design standard or a water quality standard. Most erosion and sediment control programs are cookie cutter based and apply neither a design standard or a water quality standard. Best management practices (BMPs) are applied from a preselected list and are assumed to be adequate. A design performance standard sets forth minimum requirements for design of BMPs to meet a goal of trapping efficiency or effluent standard. There is no monitoring required to prove the effectiveness. Often times this type of standard will increase the cost of construction because of the inherent conservative approach in predictive methods. Water quality standards may provide an accurate prediction of the size of controls necessary but can be extremely expensive to collect all of the necessary data and perform complex calculations for the design. Design standards are more easily used by the designer and the regulator. A preferred alternative to either of these methods is to provide a design procedure that meets a performance criteria without requiring excessive design cost. To achieve this, the design is typically expected to be slightly conservative, but considerably less conservative than if developed from a design standard.

A typical approach under the performance philosophy is to size a control to meet a water quality standard such as total suspended solids (TSS) or settleable solids (SS) standard. Trapping efficiency is commonly used to assess performance of structures, but this fails to account for incoming sediment concentration. Specific requirements for storm water management and sediment control plan approval given by the S.C. Storm Water Management and Sediment Reduction Regulations include discharge rates and hydrographs. In addition, sediment control devices must be designed to meet a removal efficiency of 80 percent of suspended solids or 0.5 ml/l peak settleable solids from a 10-year, 24-hour design storm.

POTENTIAL BENEFITS

The development of design aids was initiated to develop area specific design methods that give reasonable assurance that storm water discharges from construction sites meet desired sediment performance standards without the lengthy design process typically associated with designs developed to meet a performance standard. This approach benefits regulatory agencies and developers because the time required for design of controls for "typical" situations would be straightforward and minimized. Plan reviewers do not have to labor through detailed calculations. The use of area specific design methods provides a means of achieving sediment control without the steep learning curve associated with simulation techniques. This allows engineers to gradually gain experience and expertise in design of sediment controls. As reviewers and planners become more experienced with the procedures, they may move to modeling techniques or other methods (for large scale developments or in sensitive areas). It is still anticipated that site specific data and other procedures such as modeling be used for detailed evaluation of sediment controls. Adoption of area specific design techniques among state and local agencies helps to standardize use of the practices, reduce confusion and promote adoption of design techniques.

METHODOLOGY

The project began with site visits at numerous locations in each of the land resource areas of the state in order to see innovative methods, as well as areas needing improvement. This in-field assessment indicated the practices of choice and preferred techniques and practices to comply with state law. From this assessment a list of practices were selected. Evaluation of existing modeling capabilities led to major revisions in the SEDIMOT II Model to allow evaluation of a wide range of sediment control technologies in a seamless manner. Input data bases were generated for all major land resource regions and results from almost half a million runs of the model were used to develop simple design aids for sediment ponds, rock ditch checks and filter fences.

The tour of South Carolina construction sites revealed that channel erosion was a significant problem in many watersheds, indicating a need for adding a channel erosion component to the model since the existing routine in SEDIMOT II allows only for deposition in channels. After investigating possibilities for modifying existing routines in SEDIMOT II, it was determined that the inaccuracies in hydraulic routing when the pond routine is used for small structures and the lack of adequate sedimentation routines in the check dam routine meant that a major program modification was necessary. Because of the availability of a new hydraulic routine that is accurate over a wide range of structural sizes and types, it seemed prudent to make such a modification.

The process used was to:

- Develop a common model for reservoir routing which utilizes continuous functions for discharge and stage storage rather than discrete stage points.
- Develop physically based and tested methodologies for predicting stage discharge relationships for commonly used sediment control structures.
- Combine these routines with the CSTRS routines used in SEDIMOT II.
- Modify the model to include channel erosion.

After each of these tasks was accomplished, graphs of trapping efficiency versus ratios that contain parameters involved in hydrology and sedimentology were plotted. Numerous ratios were compared in these preliminary graphs. For example in the development of the pond design aids, ratios included volume of storage at the riser, maximum or average elevation compared to volume of runoff, peak outflow rate divided by areas at the riser, maximum or average elevation and divided by reference settling velocities for D_{15}, D_{35}, D_{50}; detention time; and riser, maximum or average surface areas. A ratio was sought that utilized inputs that could be readily obtained and that provided a grouping of data points so that a curve could be drawn that would represent a conservative estimate of the trapping efficiency. Two of the preliminary graphs are shown as Figures 1 and 2. Figure 1 shows data for two soil conditions having substantially different eroded size distributions. The Piedmont fine condition and the Sandhill coarse were used in the preliminary analysis because they represent the extremes in soils data and it was desired to have a reduced data set for the initial investigations. The ratio used in Figure 1 was not deemed adequate for use in a design aid because there is little variation in trapping efficiency for a wide range of ratios for one soil and a wide range in trapping efficiencies for the same ratio for the other soil. Figure 2 shows data for the Piedmont fine condition. In Figure 2, the trapping efficiencies are grouped much closer as a function of the ratio for the soil. Additionally, the terms required to calculate the ratio are readily obtainable. Many more alternative graphs were produced before the final ratios were selected. Prior to analyzing the data, it was anticipated that it would be necessary to have a graph for each soil condition in each land resource area (i.e., 12 graphs would be required). However, after the data were plotted and overlays were developed, it became apparent that all conditions

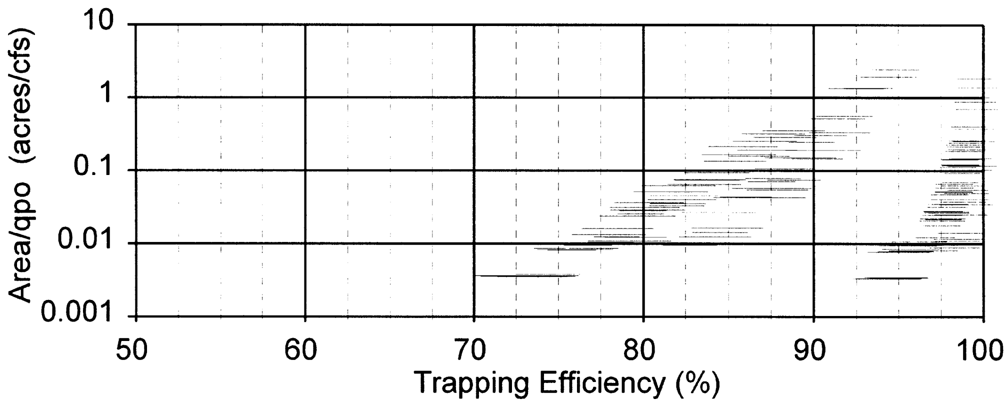

Figure 1. TE vs area/qpo—average area. Sandhills course and Piedmont fine—bare soil.

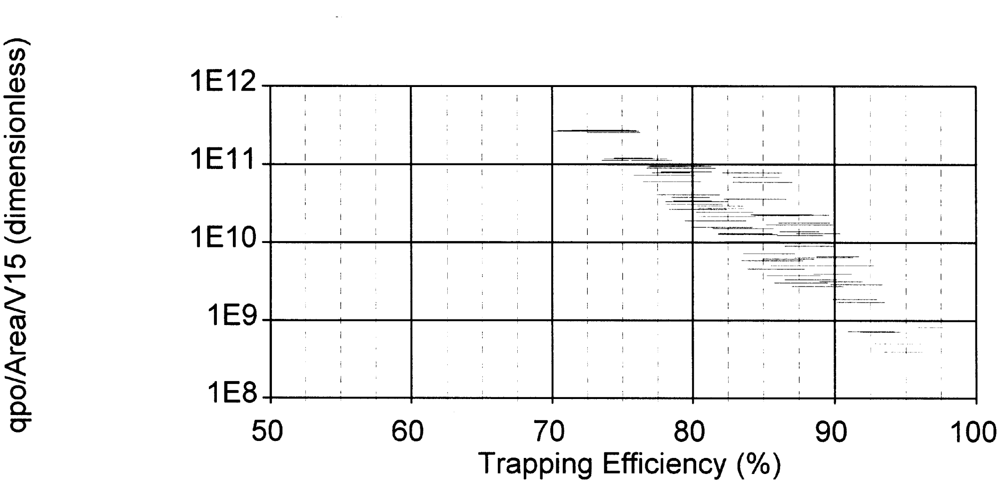

Figure 2. Trapping efficiency vs 1po/[(A)(V15)]—average area. Piedmont fine—bare soil.

except the high water table condition in the tidal area could share the same line. This finding greatly simplified the construction and use of the design aids.

The selected ratios led to graphs that can be used as an aid for designing sediment control structures that are described in subsequent sections. It should be recognized that aids such as these are developed for typical conditions in South Carolina. Other methods should be used if the situation is environmentally sensitive or hazardous. In all cases, good engineering judgment should be considered as an essential ingredient in design.

POND DESIGN AIDS

The design aids will be briefly described and then examples will be used to demonstrate their use in realistic problems. A common feature of each of the design aids is that a characteristic settling velocity for the eroded soil must be obtained. The characteristic settling velocity corresponds to an eroded particle diameter that is referred to as D_{15}. This diameter corresponds to a point on the eroded particle size distribution curve such that 15% of the particles (by weight) are equal to or smaller than this size. Estimated eroded size distributions for South Carolina soils using an adaptation of the method described by Foster, et al. (1985) have been previously developed. The procedure uses the primary particle size information reported by the USDA Soil Conservation Service as part of county soil surveys. The information is now available from the South Carolina Department of Health and Environmental Control. By plotting "fraction finer than" versus "diameter," D_{15} can be read. If D_{15} is less than 0.01 mm, then settling velocity based upon a simplified form of Stokes Law is:

$$V_s = 2.81 \times d^2 \qquad (1)$$

where V_s is settling velocity in ft/sec and d is diameter in mm. If D_{15} is greater than or equal to 0.01 mm, then settling velocity should be found using

$$\log_{10}V_s = -0.34246 \times (\log_{10}d)^2 + 0.98912 \times \log_{10}d - 0.33801 \qquad (2)$$

where V_s, is settling velocity in ft/sec and d is particle diameter in mm (Wilson, et al., 1982).

Eroded particle size distributions used in sediment control design are frequently quite different from primary size distributions that are often determined for other construction purposes. The user should note that D_{15} is often smaller for coarse textured (more sandy) because of the reduced clay content and the lack of aggregation.

Figures 3 and 4 plot the ratio $q_{po}/(A \times V_{15})$ versus percentage of trapping efficiency. For ponds, the ratio was found to be as shown below.

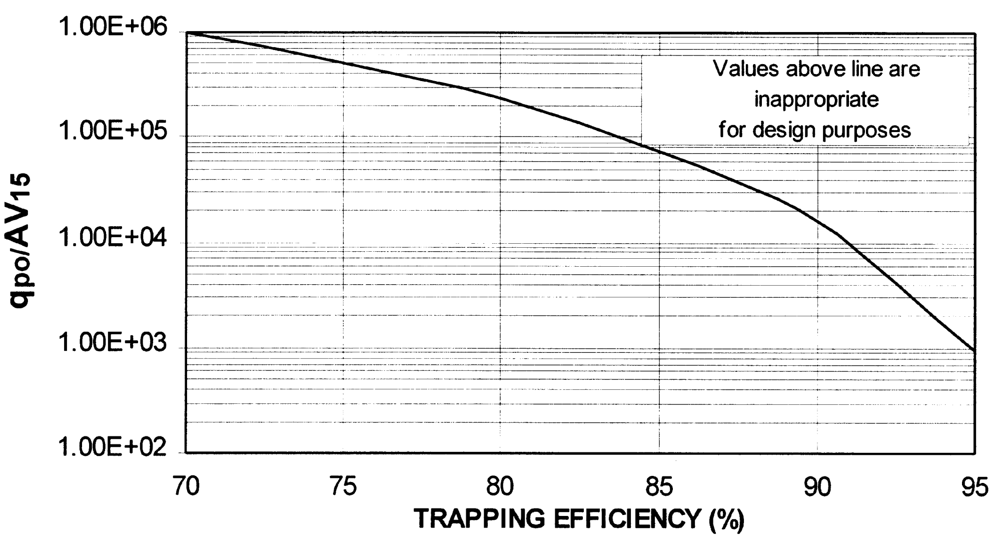

Figure 3. Design aid for estimating trapping efficiency for ponds not located in low-lying areas with high water tables.

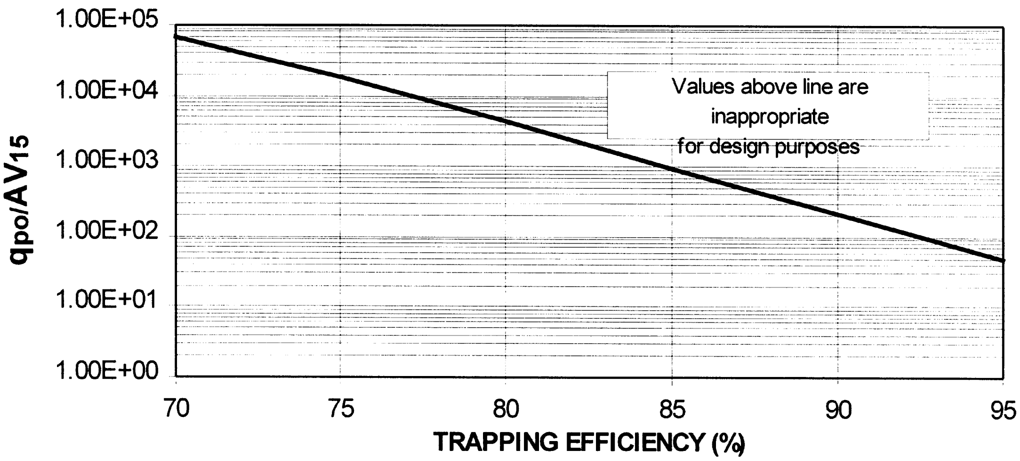

Figure 4. Design aid for estimating trapping efficiency for ponds located in low-lying areas with high water tables.

$$Ratio = q_{po}/(A \times V_{15}) \quad (3)$$

where q_{po} is peak outflow rate from the pond in cfs, A is the surface area of the pond at the riser crest in acres, and V_{15} is settling velocity, in fps, of the characteristic eroded particle corresponding to D_{15}.

Two curves are presented below. Figure 3 is for soils including Piedmont, Sandhill, Coastal and Tidal area soils, except as noted subsequently. For the Piedmont, Coastal and Tidal areas, soils are classed as either coarse (sandy loam), medium (silt loam), or fine (clay loam). Sandhill soils include coarse (sand), medium (sandy loam), and fine (silt loam) because of the prevalent textures in this region. These classifications are summarized in Table 1. Figure 4 is for tidal soils (sands and sandy loams that are classified in hydrologic soil group D because of high water table). The ratio should be less than or equal to the curve value at any given trapping efficiency. For example, at 80 percent trapping efficiency, the ratio is equal 2.2E5 for most soils as shown in Figure 3. If the ratio $q_{po}/(A \times V_{15})$ intersects the curve at a point having a trapping efficiency less than the desired value, the design is inadequate and must be revised. Upper limits on site conditions for ponds are included with Figure 3. *Ratios above the design curves are not recommended for any of the design aids*.

Constraints for use of Figures 1 and 2 are as follows;

- Watershed area less than or equal to 30 acres
- Overland slope less than or equal to 20 percent
- Outlet diameter less than or equal to 6 feet

ROCK DITCH CHECK DESIGN AIDS

Design aids for rock ditch checks were developed similarly to those for ponds. Again the D_{15} characteristic value was used for calculation of the settling velocity. The ratio for ditch checks was found to be as shown below.

$$Ratio = S \times q^{(1-b)}/(a \times V_{15}) \quad (4)$$

where S is the channel slope in percent, q is flow through the check in cfs/ft, V_{15} is the settling velocity in fps, of eroded D_{15} size particle in mm, and a and b are coefficients. The coefficients are determined from curves shown in Haan, et al. (1994). Also, given in Haan, et al. (1994) are methods to estimate flow through rock checks and overtopping potential. If the check overtops the trapping, efficiency is assumed to be zero. Three plots are shown that correspond to fine, medium and coarse textured soils. Figure 5 represents the design aid for ditch checks in coarse soils. Figures 6 and 7 represent the same for medium and fine soil conditions. Table 1 provides guidance to determine which plot is appropriate based on soil conditions.

Constraints for the use of Figures 5 through 7 are listed below.

- Watershed area is less than or equal to 5 acres
- Overland flow length is less than or equal to 500 feet
- Overland slope is less than or equal to 15 percent
- Maximum depth of the ditch is less than or equal to 6 feet

Table 1. Soil Textures by Group for Each Land Resource Area.

Land Resource Region	Coarse	Medium	Fine
Piedmont, Coastal and Tidal	Sandy Loam	Silt Loam	Clay Loam
Sand Hills	Sand	Sandy Loam	Silt Loam
Tidal (High Water Table)	Sandy Loam	Silt Loam	Clay Loam

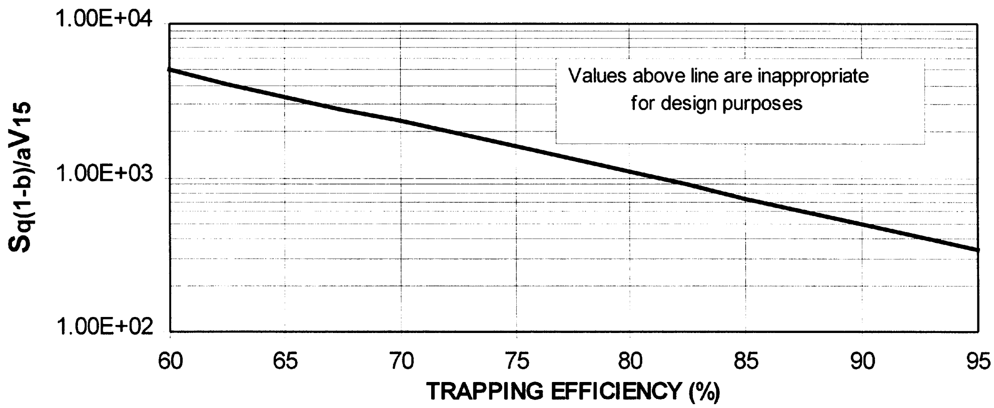

Figure 5. Design aid for estimating trapping efficiency of rock ditch checks with coarse soils.

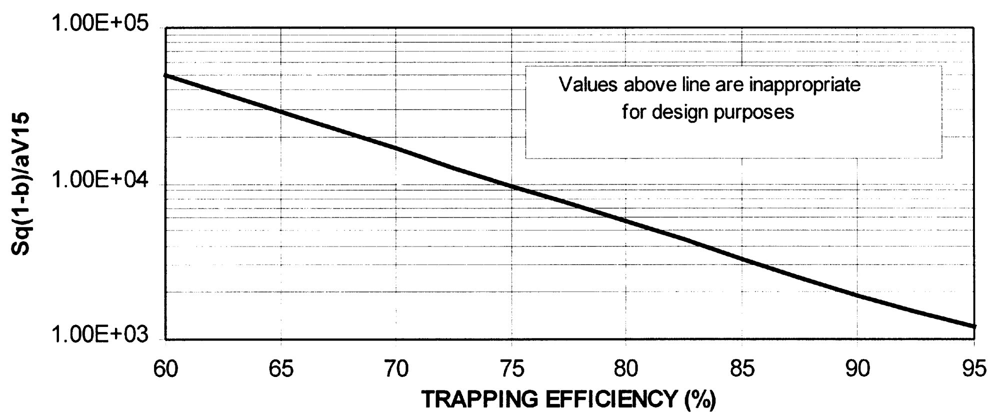

Figure 6. Design aid for estimating trapping efficiency of rock ditch checks with medium soils.

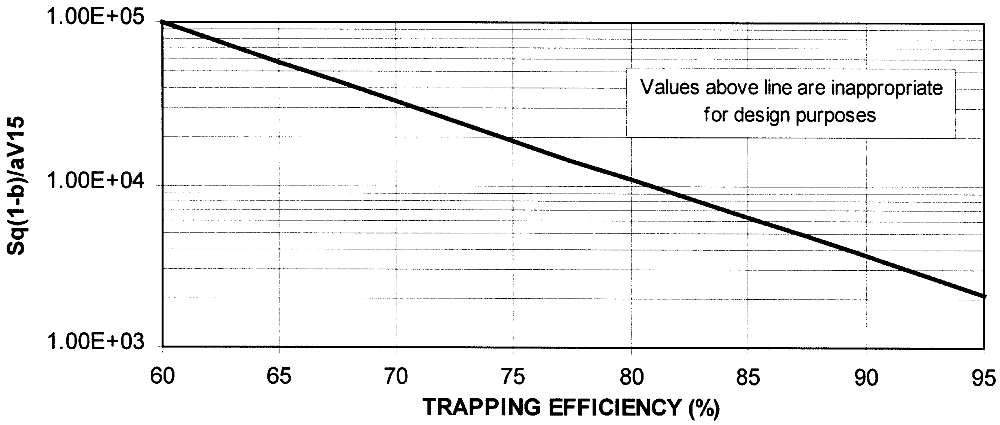

Figure 7. Design aid for estimating trapping efficiency of rock ditch checks with fine soils.

SILT FENCE DESIGN AIDS

The design aid for silt fence applies to silt fence placed in an area down slope from a disturbed area where it serves to retard flow and cause settling. Two conditions must be met for a satisfactory design.

- Trapping efficiency must meet the desired level of control.
- Overtopping of the fence must not occur.

One of the most important considerations in silt fence design is to specify regular maintenance. The silt fence design aid is a single line grouping all soil textures together. A similar procedure was used for development of the ratio as used for the ponds and rock checks. For the silt fence, the ratio was found to be as shown below.

$$Ratio = q_{po}/(V_{15} \times P_{area}) \qquad (5)$$

where q_{po} is the peak outflow through the fence, in cfs, V_{15} is settling velocity, in fps, of the eroded D_{15} size particle, and P_{area} is the potential ponding area up slope of the fence in ft².

The ponded area can be estimated by using the height of the fence available for flow, and extending a horizontal line from the fence to an intersection with the ground surface up slope of the fence. This is described by the available fence height times the ground slope. Multiply this distance by the available length of fence for ponding to obtain the potential ponding area. Then, calculate the ratio and enter the graph to determine the efficiency. Once an acceptable trapping efficiency is determined, a calculation for overtopping must be done. This calculation must be done using the slurry flow rate through the fence and checked against the incoming flow and determine if enough storage exists behind the fence to prevent overtopping. Figure 8 gives the curve for silt fence design.

Constraints for the use of Figure 8 are listed below.

- Watershed area is less than or equal 5 acres
- Overland flow length is less than or equal to 500 feet
- Overland slope is less than or equal to 6 percent
- Slurry flow rate through the fence is less than or equal to 10 gpm/ft
- Maximum height of the silt fence is less than or equal to 3 feet

ESTIMATING D_{15} AND V_{15}

A common feature used in all of the design aids is a characteristic settling velocity for a specific diameter of the eroded size distribution. For South Carolina conditions this velocity corresponds to an eroded size such that 15 percent of the sediment has particles smaller than the size specified. The procedure for empirically estimating eroded size distributions is best described by Hayes, et al. This procedure may be used with USDA Soil Survey data or site specific soil boring data. Other procedures are given by Haan, et al. (1994) for physically based estimating procedures. It is important to remember that the eroded size distribution is the most critical parameter in sizing sediment controls. The eroded particle size distributions vary greatly from primary particle size distributions that are often determined as a result of soil strength investigations for construction purposes.

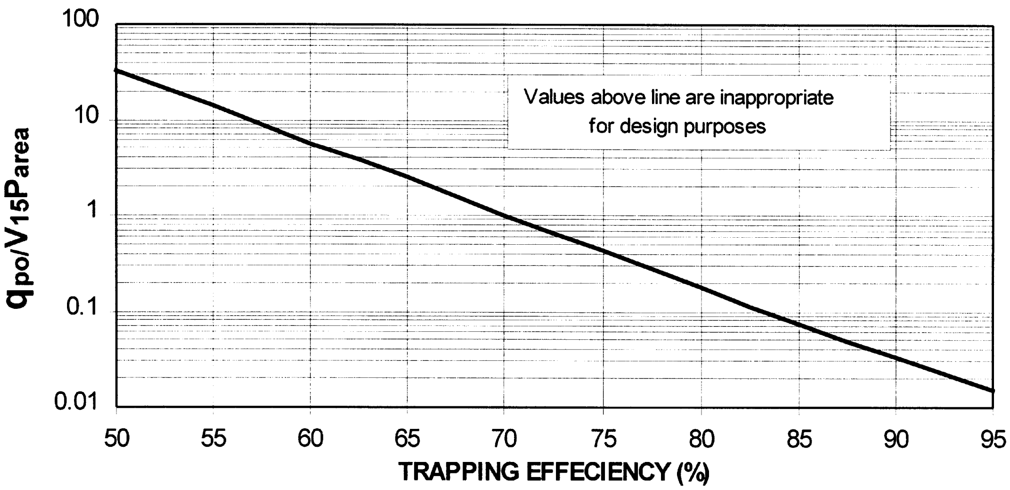

Figure 8. Design aid for silt fence trapping efficiency.

EXAMPLE PROBLEM

The example problems serve to illustrate the use of the design aids for calculation of trapping efficiency for various types of structures. Basic soils, hydrologic, and hydraulic information are combined. Methods as required by Standards for Stormwater Management and Sediment Reduction (72-300) may be used to estimate the peak flows. Other methods of estimating peak flows such as the Rational Method may be used, but are not recommended. Site specific soils information can generally be found from soil surveys. On site soil boring data may be used to generate this information as well. Hydraulic information is obtained by combining site and structural information.

In all cases, a ratio is calculated. The ratio is used to locate the point on a turning line for the specified conditions and structure. Trapping efficiency is found by reading the corresponding point on the x-axis estimating the trapping efficiency. These designs aids are intended to be slightly conservative, but use of these methods should not replace the use of good engineering judgment. Questionable results should be investigated by the engineer. Installation and maintenance should be considered. For example, it may be appropriate to add baffling to a pond in order to prevent short circuiting between the inflow and outflow locations.

It should be noted that these design aids are intended for "typical" structures. Extreme or critical conditions necessitate that more detailed analyses be conducted. For example, sensitive areas in steep terrain would be an example of an extreme situation. Also, it is assumed that the user has a working knowledge of hydrology and hydraulics.

Example Problem Pond Design

A sediment pond is to be constructed on a 30 acre commercial site in Richland County, South Carolina. The following information is available for the site based on soil, hydrologic, and hydraulic conditions.

Given:

- The eroded particle size distribution is for a coarse soil (Pelion and Fuquay mix) with D_{15} set equal to 0.024 mm because the smaller D_{15} is associated with the Pelion soil.
- Peak outflow from the pond cannot exceed 11.2 cfs.
- Allowable surface area of the pond at the riser crest is 1.67 acres.

Solution:

Determine whether the sediment pond is adequately sized for satisfactory trapping efficiency.

- Calculate settling velocity V_{15} = 0.0014 fps.
- Calculate the ratio q_{po} /(A x V_{15}) = 11.2/(1.67 x 0.0014) = 4650 = 4.6E3.
- Enter Figure 3 on y-axis with ratio = 4.6E3, go to line and turn to x-axis to read trapping efficiency.
- Trapping efficiency is equal to 93%.

REFERENCES

Foster, G. R., R. A. Young, and W. H. Niebling. 1985. "Sediment Composition for Non-Point Source Pollution Analyses." Trans. ASAE 28(1): 133–139, 146.

Haan, C. T., B. J. Barfield, and J. C. Hayes. 1994. *Design Hydrology and Sedimentology for Small Catchments*, Academic Press, 588 p.

Hayes, J. C., J. W. Price, and K. F. Holbrook. 1996. "Estimation of Eroded Particle Sizes for Sediment Control." ASAE International Meeting, Phoenix Civic Plaza, Phoenix, Arizona, July 14–18.

South Carolina Department of Health and Environmental Control. 1995. *South Carolina Stormwater Management and Sediment Control Handbook for Land Disturbance Activities*. SCDHEC Columbia, S.C.

Wilson, B. N., B. J. Barfield, and I. D. Moore. 1982. "A Hydrology and Sedimentology Watershed Model and Modeling Technique." Department of Agricultural Engineering, University of Kentucky, Lexington, Kentucky.